Wavelength shifting in InP based ultra-thin quantum well infrared photodetector via rapid thermal annealing

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***Abstract*-We have demonstrated red-shifting of the wavelength response of a bound-to-continuum p-type ultra-thin InGaAs/InP quantum well infrared photodetector after growth via rapid thermal annealing. Compared to the as-grown detector, the peak spectral response of the annealed detector was shifted to longer wavelength without any major degradation in the responsivity characteristics. Thus, the post-growth control of InGaAs/InP quantum well composition profiles by rapid thermal annealing offers unique opportunities to fine tune various aspects of a photodetector's response.**

I. INTRODUCTION

One of the distinct advantages of the quantum well approach is the ability to produce multi-band or multi-color detectors, which arc desirable for future high-performance IR systems [1]. In all cases, the detection wavelengths are chosen prior to growth by designing the layer structure accordingly. Interdiffusion offers the flexibility to modify the properties of the materials after growth. It is possible to modify the energy levels of quantum well infrared photodetector (QWIP) after growth by rapid thermal annealing (RTA) for realizing multi-wavelength response. The post growth wavelength shifting of QWIPs by RTA is accomplished by dielectric encapsulating the QWIP and exposing it to high temperatures for a short period of time[2]. The quantum well is changed from a square well, with sharp interfaces, to an error-function shaped well, with a corresponding change in the confined energy levels[3,4]. This tunability is of interest to IR detector applications as it would facilitate the fine tuning of the peak detector response of as-grown detector to a particular desired operational wavelength, The present article describes the effect of RTA on important detector characteristics of QWIPs such as the detector photoresponse and absolute responsivity.

11. GROWTH AND MATERIAL CHARACTERIZATION

Ultra-thin p-type InGaAs/InP QWIPs were grown by gas source molecular beam epitaxy (GSMBE) system on semi-insulating (001) InP substrates. [5]. The p-type structure consisted of 30 periods of 10Å Be center doped ($3x10^{18}cm^{-3}$) $In_{0.53}Ga_{0.47}As$ quantum wells (QWs) and 500A Be doped ($1x10^{17}$ cm^{-3}) InP barriers sandwiched between 5000Å Be doped ($3x\ 10^{18}\ cm^{-3}$) $In_{0.53}Ga_{0.47}As$ contacts on InP substrate. In all studies, prior to anneding,, the samples are first degreased in trichloromethane, acetone, and methanol followed by a light surface etch using NH_40H. Then, a 1500Å SiO_2 encapsulant is deposited by plasma enhanced chemical vapor deposition. Rapid thermal annealing is performed in an AET RTA reactor with 10 seem of N_2 flowing. The temperature is stabilized at 200°C prior to the high temperature anneal. The material quality and optical properties of the as-grown and annealed InGaAs/InP MQW samples arc investigated using cross-sectional transmission electron microscopy (TEM), and photoluminescence measurements (PL). Cross-sectional transmission electron microscopy study was performed at 120KV on a Phillips CM 12 microscope. 6K PL measurements were performed with 514nnl excitation from an argon ion laser. The PI. was dispersed by a lrn single grating spectrometer and then detected with a Ge detector.

The cross-sectioned TEM micrographs arc shown in Fig.1 for (a) an as-growth MQW and (b) an RTA MQW annealed at 800°C for 30 seconds. No defects or dislocations arc observed for both as-grown and annealed MQW regions. Fig. 2 illustrates the 6K PL spectra of the samples capped with $Si0_2$ and followed by RTA at temperatures 700°C, 800°C, and 900°C for 30 seconds. The dependent of the

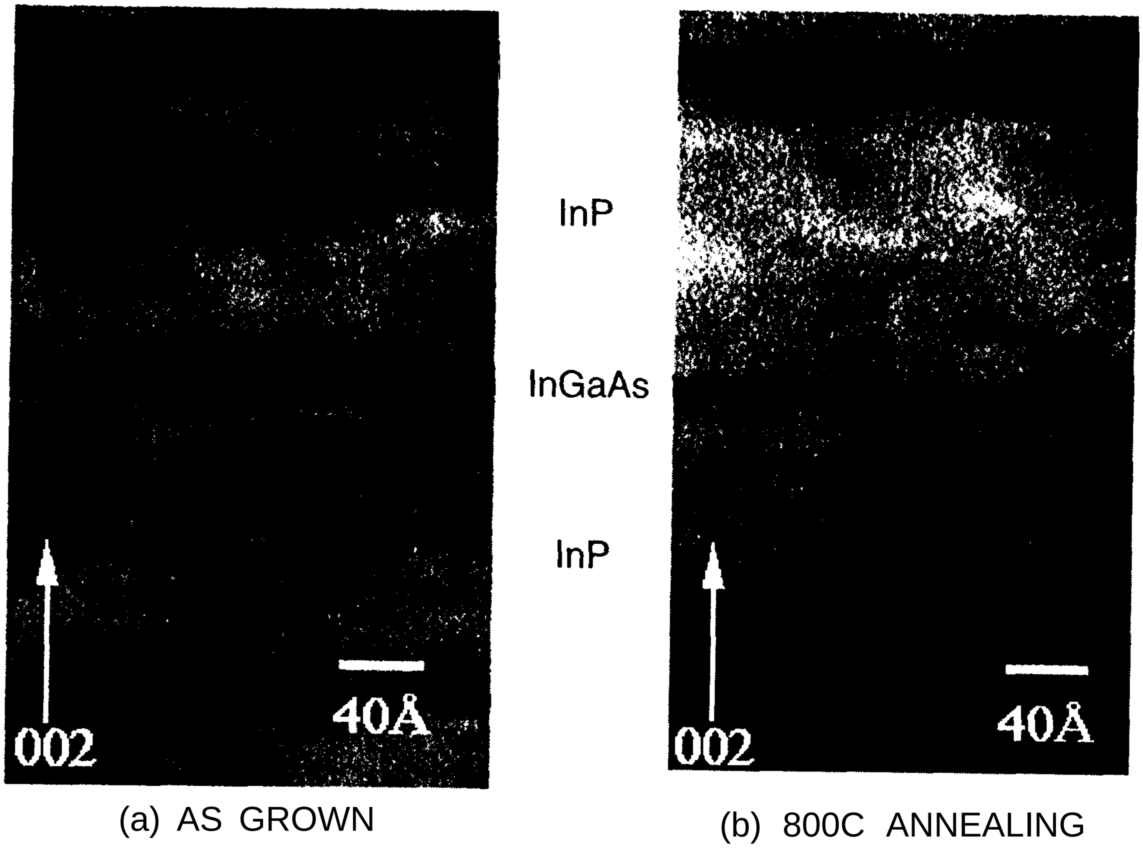

Figure 1: Cross-sectional TEM of the. (a) as-grown, and (b) RTA (800°C for 30s) MQW structures.

blue shift in PL peak emission energies on temperature was observed (- 24.0meV @700°C , - 130.2meV @800°C, and 292.5 meV @ 900°C). Fig. 3 illustrates the 6K PL spectra of the sample after RTA treatments, carried out al a temperature of 800 °C for 20, 40, and 60s, respectively. In addition, Fig. 4 show no significant degradation of the PL linewidth up to 800°C RTA. In summary, we have achcived strong and homogeneous intermixing in InGaAs/InP QWS using SiO_2 taping and subsequently annealing. No significant degradation of optical properties was observed up to 800°C. A substantial PL blue shift, as much as 130.2 meV, was found in the structure and the value of the shift can be controlled by the anneal time, In addition, beyond 800°C RTA, annealed QWIP structure also exhibits a reduction in peak luminescent intensity, which may be due to the overall broadening of the peak response as well as any defects that the annealing process might have introduced.

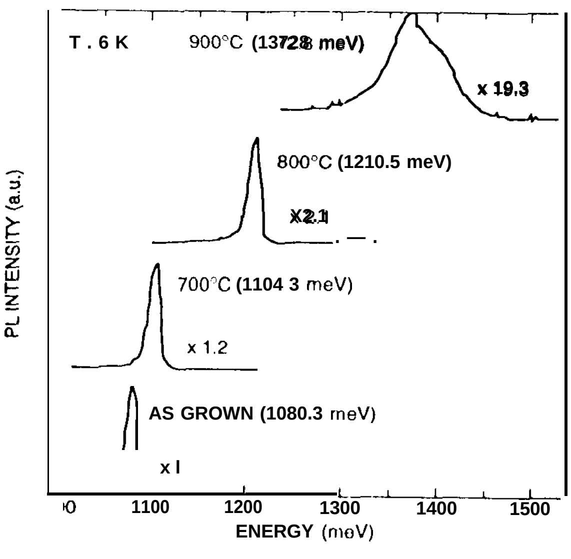

Figure 2: Photoluminescence spectra at 6K of the as-grown and RTA (700°C, 800°C, and 900°C for 30s) MQW structures.

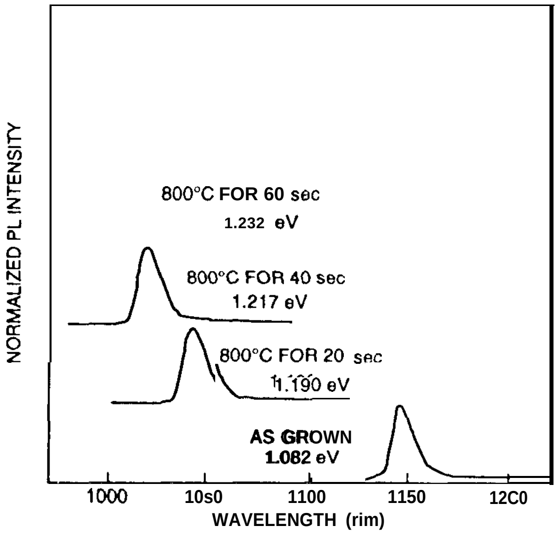

Figure 3: **6K** photoluminescence spectra of the as-grown and RTA treatments (800°C for 20s, 40s, and 60s).

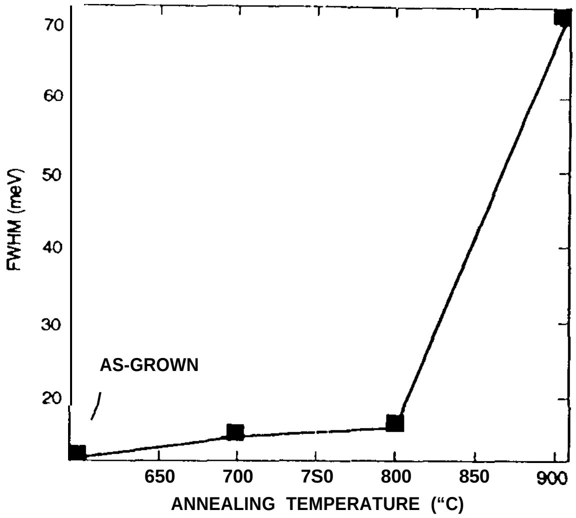

Figure 4: **6K** photoluminescence line width of the as-grown and RTA (700°C, 800°C, and 900°C for 30s) MQW structures.

HI. DEVICE CHARACTERIZATION

Quantum -well infrared detectors were fabricated from the as-grown and SiO_2-encapsulated RTA (800°C for 40s) samples into 200μm circular mesas by etching through the upper conact layer and the multiple quantum well structure down to the bottom contact layer . Ohmic contacts to the p-doped contact layers are subsequently formed by evaporating and alloying Ti/Pt/Au metallization. Spectral response, and absolute responsivity measurements on the as-grown and RTA QWIPs were performed with the detectors mounted on a stage which is in thermal contact with the cold end of a continuous flow helium cyrostat. The detectors are connected to an external bias circuit, and bias supplied using a battery in series with a large resistor. In measuring the relative spectral response, a grating monochromator, a Bomem MB series FTIR, a phase locked amplifier, a reference pyroelectric detector, a chopper, and a glowbar were used. The unpolarized light was incident normal to the 45” facet on the detector. The absolute magnitude of the responsivity was determined by measuring the photocurrent with a calibrated blackbody source at 1000K. The conversion to absolute units was carried out by taking the unpolarized blackbody radiation, which was filtered using a variable narrow-band infrared filter tuned to the peak wavelength. Also, taken into account were the reflection losses at the GaAs interface and the throughput of the optical system. Fig. 6 & 7 show the photoresponse for both the as-grown and RTA detector with bias. The peak response wavelengths measured arc -4.55pm (80Kand 5.9V) for the as-grown detector and ~7.0μm (4.5Kand 4V) for the RTA detector. Since the ground state is higher and the **effective barrier height** is lower in the RTA detector than in the as-grown detector, the peak response wavelength of the RTA detector experiences a longwavelength shift. The peak absolute responses are calculated to be ~2.5mA/W (80Kand 5.9V) for the as-grown detector and ~2.0mA/W (4.5K and 4V) for the RTA detector from the blackbody and relative spectral response measurements. The peak responsivity of the RTA detector is of a similar magnitude compared to the as-grown detector. Although the broadened absorption spectrum of the RTA detector can result in a reduced spectral response, we believe that the dominant reduction is a consequence of the out-diffusion of the Be dopant from the well and the increased dark current from the RTA detector structure. The small reduction in the response may still be acceptable for the focal plane array detector applications [6].

IV, CONCLUSION

In conclusion, wc have demonstrated that RTA can be employed to both shift the operating wavelength and to broaden the response of an ultra-thin p-type

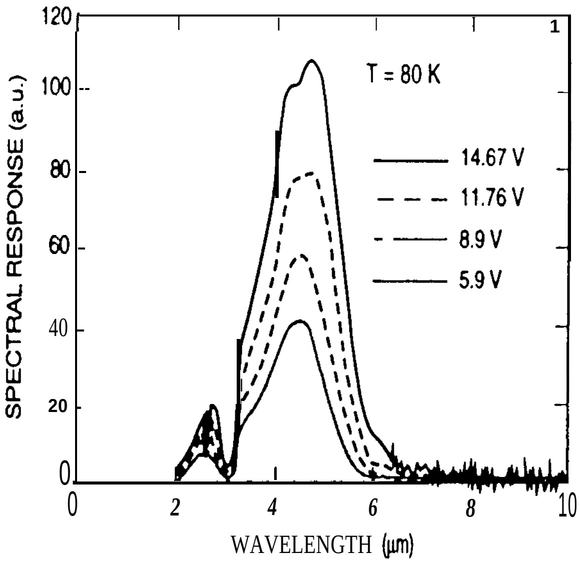

Figure 6: Bias dependence of the spectral response measured for the **as-grown** QWIP at 80K.

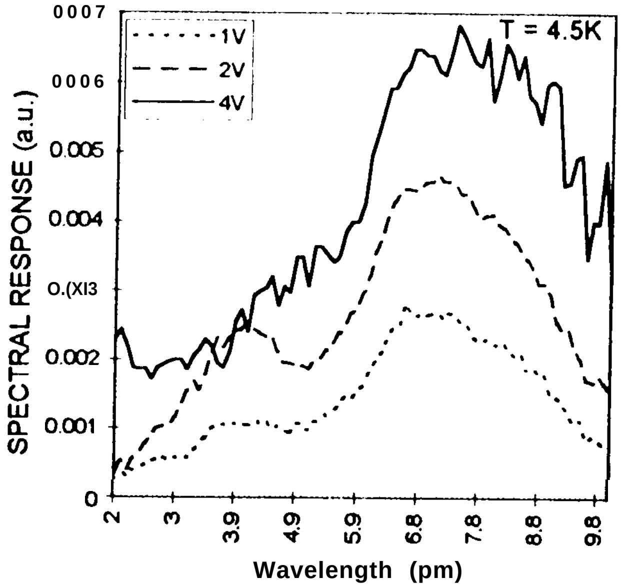

Figure 7: Bias dependence of the spectral response measured for the RTA QWIP at 4.5K.

InGaAs/InP quantum well infrared photodetector following intermixing of the well and barrier layers during rapid thermal annealing. The use of RTA changes the well profile of a QWIP and peak wavelength, but the reduced responsivity indicates **that this technique is limited** for sensitive IR detectors. Recent advances in growth, complimented by innovative structures (random gratings and reflector layers) should offset any degradation in performance. This makes feasible integration of multiple-colored pixels.

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